NASA TT F-10,408

NASA TT F-10,408

MODELLING ENERGY EXCHANGE PROCESSES IN ECOLOGICAL SYSTEMS

A. B. Rubin

(Academy of Sciences of the USSR)

Translation of "Modelirovaniye protesessov energoobmena v ekologicheskikh sistemakh". 17th International Astronautical Congress, Madrid, 9-15 October 1966.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON NOVEMBER 1966

NASA TT F-10,408

MODELLING ENERGY EXCHANGE PROCESSES IN ECOLOGICAL SYSTEMS

A. B. Rubin

(Academy of Sciences of the USSR)

ABSTRACT

The author discusses the mathematical modelling of the process of energy exchange between separate links in an ecological complex. An artificial ecological complex is viewed as a closed system, with energy and mass exchange being a sequential, branched chain. A chain consisting of three components is considered as an example.

An analysis of the structure of artificial ecological systems shows the great importance of calculating the interaction between the separate components of an ecological complex. It is just the inner dynamic characteristics of a system which can determine the trend and stability of energy exchange between the links of an ecological chain under normal and unfavorable conditions. Mathematical modelling of the process of energy exchange between separate links of a system is an essential and in many cases, an indispensable stage in the construction of an ecological complex. /1*

An artificial ecological complex can be viewed as a closed system consisting of separate interrelated links which function due to external solar energy. The energy and mass exchange in such a system can be thought of as a sequential, branched chain for transfer of substance and energy between the links. Let our system consist of n links in series (A, B, C....) each of which can be a separate component, including components of nonbiological origin, in an ecological chain:

$$
\begin{tikzcd}
 & & E_2 \arrow[d] & E_4 \arrow[d] & E_6 \arrow[d] & \\
{} \arrow[r, "E_1"] & A \arrow[r, "K_1"] & B \arrow[r, "K_2"] \arrow[d] & C \arrow[r, "K_3"] \arrow[d] & D \arrow[r, "K_4"] \arrow[d] & {} \\
 & & E_3 & E_5 & E_7 &
\end{tikzcd}
\qquad \mathrm{I}
$$

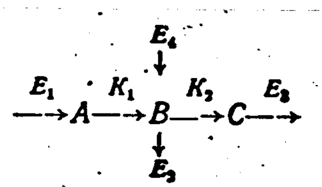
The kinetics of transforming separate components in such a chain is described as a system of nonlinear differential equations of the type: /2

*Numbers given in the margin indicate the pagination in the original foreign text.

$$\frac{dB}{dt} = K_1AB + E_2B - E_3B - K_2BC \,, \qquad (1)$$

where the terms K_1AB and $-K_2BC$ describe the interaction in the chain itself and the terms $+E_2B - E_3B$ correspond to side reactions of the first order of each of the components. When the main chain is disrupted the changes in the component B will be determined only by the constants E_2 and E_3, whereas the expression $(E_2 - E_3)$ may have any sign and be equal to zero.

By way of example, we will discuss a chain consisting of three components:



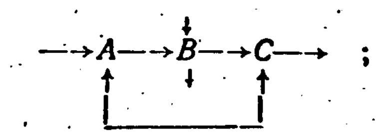
II

According to the model shown in II the equations system for the energy exchange has the form:

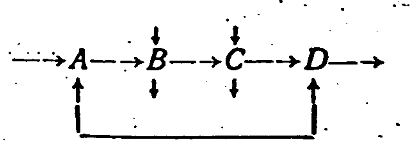
$$\begin{aligned} A' &= E_1A - K_1AB \,; \\ B' &= K_1AB - E_2B + E_4B - K_2BC \,; \\ C' &= K_2BC - E_3C \,. \end{aligned} \qquad (2)$$

An analysis of this system (2) conducted by the methods of qualitative theory of differential equations shows the existence of a set of particular points each of which is a particular point of the "center" type and defines the fluctuating mode of energy exchange processes.

A consideration of several other models of energy exchange leads to a similar conclusion. For example:



III



IV

There also are many others. One thing in common which all these models have is that the inflow and outflow of energy (mass) for any component in the chain depends on the concentration of the donor and the acceptor of the co-members in the chain (Equation (1)). The existence of particular points of the "center" type make it possible to speak of a stable fluctuating mode of energy exchange in the systems discussed. It is possible to determine the necessary and sufficient conditions of relationships between coefficients (energy exchange constants) due to which, in the system, there is a stable periodic mode. For Model II, for example, one such condition is the expression: /3

$$E_1E_2 + E_1E_4\frac{K_1}{K_3} > 0 .$$

In the models discussed there is either a stable fluctuating mode of energy exchange, or the system is completely unable to achieve a stationary state.

An investigation of the thermodynamic properties of fluctuating models and computation of the value of the rate of increment of entropy (dissipation of enery) shows that the value of this equation is zero. This is related with attaining a stationary state in an open system wherein the rate of inflow of entropy is equal to the rate of outflow from the system. In many cases this may be caused by the cyclic nature of the transformation of components in the system.

In a general theoretical discussion of the processes of energy exchange a determination should be made of the energy indicators of the effectiveness and dynamics of the processes which take place in the separate links. Thus, the coupling of the autotrophic and heterotrophic links requires knowledge of rates and energy drops during the exchange in the chain of intermediate compounds which take part mainly in photosynthesis and breathing. The molecular and submolecular characteristics of the energy and mass exchange in separate links give information about the internal state of an organism. Obtaining such information is completely essential for predicting the behavior of biological objects in time and also for the construction of automatic control systems in ecological complexes. It is essential that under conditions of artificial association the process of obtaining information be continuous and at the same time, have no significant effect on the state of the biological object. Apparently such a requirement precludes the use of complex biochemical analyses for these purposes. The use of optical methods, specifically the recording of chemiluminescent photosynthesizing organisms, on the contrary, is very promising in this regard. For recording the light from chemiluminescence use is made of low-noise photoelectronic multipliers which operate as photon counters. Attenuation of chemiluminescence is studied at various intervals of time following the cessation of light excitation of an object which is placed periodically in front of the photocathode of the recording biological counter. Experiments show that the intensity of afterglow, 10—20 seconds after cessation of light, excitation is connected with the rate of separation of oxygen during photosynthesis. At the same time, the intensity of brightness after 1—2 minutes under the same conditions is in keeping with the processes of accumulation of energy in high-energy phosphate bonds during photosynthesis. /4

The method of chemiluminescence makes it possible to judge the rate of the processes of photosynthesis. The nature of this luminescence depends largely on the physiological condition of the object and therefore is an indicator of it. Extensive development of the methods for recording the condition of biological objects is necessary to obtain the initial data needed for making general theoretical calculations in connection with coupling links having different qualities in an ecological system.

REFERENCES

1. Rubin, A. B., Fokht, A. S., and Venediktov, P. S.: "Biofizika," No. 11, p. 299, 1966. /5

2. Rubin, A. B., Fokht, A. S., Naumov, N. P.: "Zhurnal obshchey biologii," Vol. 27, p. 1966, 1966.

Translated for National Aeronautics and Space Administration by INTERNATIONAL INFORMATION INCORPORATED.